

WHAT IS CLAIMED IS:

1           ①.     A hearing aid, comprising:  
2                 an input signal channel providing digital input signals;  
3                 a signal path adapted to process said digital input signals in accordance  
4 with a predetermined signal processing algorithm to produce a digital output signal,  
5 wherein said signal path further comprises at least one signal processing function  
6 operating on a warped frequency scale, and wherein said at least one signal processing  
7 function includes at least one spectral enhancement algorithm; and  
8                 an output conversion means adapted to convert said output signals to an  
9 audio output.

1                 2.     The hearing aid of claim 1, wherein said at least one signal  
2 processing function further comprises a plurality of cascaded all-pass filters.

1                 3.     The hearing aid of claim 1, wherein said warped frequency scale  
2 approximates a Bark scale.

1           ④.     A frequency-warped processing system, comprising:  
2                 an input signal channel providing digital input signals;  
3                 a plurality of cascaded all-pass filters, wherein said digital input signals  
4 pass through said plurality of cascaded all-pass filters, and wherein said plurality of  
5 cascaded all-pass filters output a sequence of delayed samples;  
6                 means for applying a frequency domain transform on said sequence of  
7 delayed samples, wherein a warped sequence results from said frequency domain  
8 transform applying means;  
9                 means for calculating a plurality of frequency domain level estimates from  
10 said warped sequence;  
11                 means for calculating a plurality of frequency domain gain coefficients  
12 from said plurality of frequency domain level estimates;  
13                 means for calculating a plurality of spectral enhancement gain coefficients  
14 from said warped sequence;

15 means for calculating a plurality of compression-spectral enhancement  
16 gain coefficients from said plurality of frequency domain gain coefficients and said  
17 plurality of spectral enhancement gain coefficients;  
18 means for applying an inverse frequency domain transform on said  
19 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-  
20 domain filter coefficients of a compression gain filter result from said inverse frequency  
21 domain transform applying means; and  
22 means for convolving said sequence of delayed samples with said set of  
23 time-domain filter coefficients to produce a digital output signal.

1 5. The frequency-warped processing system of claim 4, said means  
2 for calculating said plurality of spectral enhancement gain coefficients further comprising  
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm raises a  
4 power spectrum comprised of said plurality of frequency domain level estimates to a  
5 power greater than 1.

1 6. The frequency-warped processing system of claim 4, said means  
2 for calculating said plurality of spectral enhancement gain coefficients further comprising  
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm amplifies  
4 a plurality of peaks of said warped sequence.

1 7. The frequency-warped processing system of claim 6, wherein said  
2 spectral enhancement algorithm further comprises means for identifying said plurality of  
3 peaks, said identifying means including means for applying a second-difference operator  
4 to said warped sequence.

1 8. The frequency-warped processing system of claim 4, said means  
2 for calculating said plurality of spectral enhancement gain coefficients further comprising  
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm includes  
4 means for forming an unsmeared warped sequence, and means for calculating the  
5 difference between said warped sequence and said unsmeared warped sequence.

1 9. The frequency-warped processing system of claim 4, further  
2 comprising a hearing aid, wherein the frequency-warped processing system is  
3 incorporated within said hearing aid.

1                   10.     The frequency-warped processing system of claim 4, wherein said  
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1                   11.     The frequency-warped processing system of claim 4, further  
2 comprising means for windowing said sequence of delayed samples, wherein a windowed  
3 sequence of delayed samples results from said windowing means, and wherein said  
4 warped sequence results from applying said frequency domain transform to said  
5 windowed sequence of delayed samples.

1                   12.     The frequency-warped processing system of claim 4, further  
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said  
3 digital output signals to analog output signals.

1                   13.     The frequency-warped processing system of claim 12, further  
2 comprising an output transducer, said output transducer converting said analog output  
3 signals to an audio output.

1                   14.     The frequency-warped processing system of claim 4, said plurality  
2 of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1                   15.     The frequency-warped processing system of claim 4, said sequence  
2 of delayed samples comprising 16 samples.

1                   16.     The frequency-warped processing system of claim 4, further  
2 comprising a digital processor, wherein said digital processor is adapted to provide said  
3 frequency domain transform applying means, said frequency domain level estimates  
4 calculating means, said frequency domain gain coefficients calculating means, said  
5 spectral enhancement gain coefficients calculating means, said inverse frequency domain  
6 transform applying means, and said means for convolving said sequence of delayed  
7 samples.

1                   17.     The frequency-warped processing system of claim 16, wherein said  
2 digital processor comprises a software programmable digital signal processor.

1                   18.     The frequency-warped processing system of claim 4, wherein said  
2 frequency domain transform applying means uses a transform selected from the group

3 consisting of discrete Fourier transforms, fast Fourier transforms, Goertzel transforms,  
4 and discrete cosine transforms.

1 19. The frequency-warped processing system of claim 4, further  
2 comprising:

3 an input transducer, said input transducer converting audio input signals to  
4 analog input signals; and

5 an analog-to-digital converter, said analog-to-digital converter converting  
6 said analog input signals to said digital input signals.

1 20. The frequency-warped processing system of claim 4, further  
2 comprising:

3 a digital-to-analog converter, said digital-to-analog converter converting  
4 said digital output signals to analog output signals; and

5 an output transducer, said output transducer converting said analog output  
6 signals to an audio output.

1 21. A frequency-warped processing system, comprising:

2 an input signal channel providing digital input signals;

3 an input data buffer, said input data buffer holding at least one block of  
4 data comprised of a portion of said digital input signals;

5 a plurality of cascaded all-pass filters, wherein a first block of said digital  
6 input signals pass from said input data buffer through said plurality of cascaded all-pass  
7 filters, and wherein said plurality of cascaded all-pass filters output a first sequence of  
8 delayed samples;

9 means for windowing a first portion of said first sequence of delayed  
10 samples, wherein a first windowed sequence of delayed samples results from said  
11 windowing means;

12 means for applying a first frequency domain transform on said first  
13 windowed sequence of delayed samples, wherein a first warped sequence results from  
14 said first frequency domain transform applying means;

15 means for calculating a first plurality of frequency domain level estimates  
16 of said first warped sequence;

17 means for calculating a first plurality of spectral enhancement gain  
18 coefficients from said first warped sequence;

19 means for windowing a second portion of said first sequence of delayed  
 20 samples, wherein a second windowed sequence of delayed samples results from said  
 21 windowing means;  
 22 means for applying a second frequency domain transform on said second  
 23 windowed sequence of delayed samples, wherein a second warped sequence results from  
 24 said second frequency domain transform applying means;  
 25 means for calculating a second plurality of frequency domain level  
 26 estimates of said second warped sequence;  
 27 means for calculating a first plurality of spectral enhancement gain  
 28 coefficients from said first warped sequence;  
 29 means for summing said first and second plurality of spectral enhancement  
 30 gain coefficients, wherein a summed first and second plurality of spectral enhancement  
 31 gain coefficients results from said summing means;  
 32 means for summing said first and second plurality of frequency domain  
 33 level estimates, wherein a summed first and second plurality of frequency domain level  
 34 estimates results from said summing means;  
 35 means for normalizing said summed first and second plurality of frequency  
 36 domain level estimates, wherein a normalized first and second plurality of frequency  
 37 domain level estimates results from said normalizing means;  
 38 means for calculating a plurality of frequency domain gain coefficients  
 39 from said normalized first and second plurality of frequency domain level estimates;  
 40 means for calculating a plurality of compression-spectral enhancement  
 41 gain coefficients from said plurality of frequency domain gain coefficients and said  
 42 summed first and second plurality of spectral enhancement gain coefficients;  
 43 means for applying an inverse frequency domain transform on said  
 44 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-  
 45 domain filter coefficients of a compression gain filter result from said inverse frequency  
 46 domain transform applying means; and  
 47 means for convolving a second sequence of delayed samples with said  
 48 time-domain filter coefficients, said second sequence of delayed samples produced by a  
 49 second block of said digital input signals passing from said input data buffer through said  
 50 plurality of cascaded all-pass filters, wherein a digital output signal results from said  
 51 convolving means.

1                   22.     The frequency-warped processing system of claim 21, said means  
2     for calculating said first and second plurality of spectral enhancement gain coefficients  
3     further comprising a spectral enhancement algorithm, wherein said spectral enhancement  
4     algorithm raises a power spectrum comprised of said plurality of frequency domain level  
5     estimates to a power greater than 1.

1                   23.     The frequency-warped processing system of claim 21, said means  
2     for calculating said first and second plurality of spectral enhancement gain coefficients  
3     further comprising a spectral enhancement algorithm, wherein said spectral enhancement  
4     algorithm amplifies a plurality of peaks of said warped sequence.

1                   24.     The frequency-warped processing system of claim 23, wherein said  
2     spectral enhancement algorithm further comprises means for identifying said plurality of  
3     peaks, said identifying means including means for applying a second-difference operator  
4     to said warped sequence.

1                   25.     The frequency-warped processing system of claim 21, said means  
2     for calculating said first and second plurality of spectral enhancement gain coefficients  
3     further comprising a spectral enhancement algorithm, wherein said spectral enhancement  
4     algorithm includes means for forming an unsmeared warped sequence, and means for  
5     calculating the difference between said warped sequence and said unsmeared warped  
6     sequence.

1                   26.     The frequency-warped processing system of claim 21, further  
2     comprising a hearing aid, wherein the frequency-warped processing system is  
3     incorporated within said hearing aid.

1                   27.     The frequency-warped processing system of claim 21, wherein said  
2     plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1                   28.     The frequency-warped processing system of claim 21, further  
2     comprising a digital-to-analog converter, said digital-to-analog converter converting said  
3     digital output signals to analog output signals.

1                   29.     The frequency-warped processing system of claim 28, further  
2     comprising an output transducer, said output transducer converting said analog output  
3     signals to an audio output.

1                   30.     The frequency-warped processing system of claim 21, said  
2     plurality of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1                   31.     The frequency-warped processing system of claim 21, further  
2     comprising a digital processor, wherein said digital processor is adapted to provide said  
3     windowing means, said means for applying said first and second frequency domain  
4     transforms, said means for calculating said first and second plurality of frequency domain  
5     level estimates, said summing means, said normalizing means, said frequency domain  
6     gain coefficients calculating means, said inverse frequency domain transform applying  
7     means, and said convolving means.

1                   32.     The frequency-warped processing system of claim 21, wherein said  
2     means for applying said first and second frequency domain transforms use a transform  
3     selected from the group consisting of discrete Fourier transforms, fast Fourier transforms,  
4     Goertzel transforms, and discrete cosine transforms.

1                   33.     The frequency-warped processing system of claim 21, further  
2     comprising:  
3                   an input transducer, said input transducer converting audio input signals to  
4     analog input signals; and  
5                   an analog-to-digital converter, said analog-to-digital converter converting  
6     said analog input signals to said digital input signals.

1                   34.     The frequency-warped processing system of claim 21, further  
2     comprising:  
3                   a digital-to-analog converter, said digital-to-analog converter converting  
4     said digital output signals to analog output signals; and  
5                   an output transducer, said output transducer converting said analog output  
6     signals to an audio output.

1                   35.     The frequency-warped processing system of claim 21, wherein said  
2 windowing means provides a 50 percent overlap of said first and second pluralities of  
3 frequency domain level estimates.

1                   36.     The frequency-warped processing system of claim 21, wherein a  
2 quantity of samples corresponding to said first block of said digital input signals is  
3 equivalent to a quantity of first order all-pass filters corresponding to said plurality of  
4 cascaded all-pass filters.

1                   37.     The frequency-warped processing system of claim 36, wherein said  
2 first portion of said first sequence of delayed samples is comprised of a first half of said  
3 first sequence of delayed samples and said second portion of said first sequence of  
4 delayed samples is comprised of a second half of said first sequence of delayed samples.

1                   (38)    A frequency-warped processing system, comprising:  
2                   an input signal channel providing digital input signals;  
3                   an input data buffer, said input data buffer holding a block of data of size  
4 M comprised of a portion of said digital input signals;  
5                   a plurality of cascaded all-pass filters comprised of 2M cascaded all-pass  
6 filters, wherein a first block of said digital input signals pass from said input data buffer  
7 through said plurality of cascaded all-pass filters to form a first sequence of delayed  
8 samples and wherein a second block of said digital input signals pass from said input data  
9 buffer through said plurality of cascaded all-pass filters to form a second sequence of  
10 delayed samples, and wherein said first sequence of delayed samples and said second  
11 sequence of delayed samples form a combined sequence of delayed samples;  
12                   means for windowing a first portion of said combined sequence of delayed  
13 samples, wherein said first portion is of size M, wherein a windowed sequence of delayed  
14 samples results from said windowing means;  
15                   means for applying a 2M-point frequency domain transform on said  
16 windowed sequence of delayed samples, wherein a warped sequence results from said  
17 frequency domain transform applying means;  
18                   means for calculating a plurality of frequency domain level estimates of  
19 said warped sequence;



20 means for calculating a plurality of frequency domain gain coefficients  
21 from said plurality of frequency domain level estimates;  
22 means for calculating a plurality of spectral enhancement gain coefficients  
23 from said warped sequence;  
24 means for calculating a plurality of compression-spectral enhancement  
25 gain coefficients from said plurality of frequency domain gain coefficients and said  
26 plurality of spectral enhancement gain coefficients;  
27 means for applying an inverse frequency domain transform on said  
28 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-  
29 domain filter coefficients of a compression gain filter result from said inverse frequency  
30 domain transform applying means; and  
31 means for convolving a second portion of said combined sequence of  
32 delayed samples with said set of time-domain filter coefficients, wherein said second  
33 portion is of size M, wherein a digital output signal results from said convolving means.

1 39. The frequency-warped processing system of claim 38, said means  
2 for calculating said plurality of spectral enhancement gain coefficients further comprising  
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm raises a  
4 power spectrum comprised of said plurality of frequency domain level estimates to a  
5 power greater than 1.

1 40. The frequency-warped processing system of claim 38, said means  
2 for calculating said plurality of spectral enhancement gain coefficients further comprising  
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm amplifies  
4 a plurality of peaks of said warped sequence.

1 41. The frequency-warped processing system of claim 40, wherein said  
2 spectral enhancement algorithm further comprises means for identifying said plurality of  
3 peaks, said identifying means including means for applying a second-difference operator  
4 to said warped sequence.

1 42. The frequency-warped processing system of claim 38, said means  
2 for calculating said plurality of spectral enhancement gain coefficients further comprising  
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm includes

4 means for forming an unsmeared warped sequence, and means for calculating the  
5 difference between said warped sequence and said unsmeared warped sequence.

1 43. The frequency-warped processing system of claim 38, further  
2 comprising a hearing aid, wherein the frequency-warped processing system is  
3 incorporated within said hearing aid.

1 44. The frequency-warped processing system of claim 38, wherein said  
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 45. The frequency-warped processing system of claim 38, further  
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said  
3 digital output signals to analog output signals.

1 46. The frequency-warped processing system of claim 45, further  
2 comprising an output transducer, said output transducer converting said analog output  
3 signals to an audio output.

1 47. The frequency-warped processing system of claim 38, said  
2 plurality of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 48. The frequency-warped processing system of claim 38, further  
2 comprising a digital processor, wherein said digital processor is adapted to provide said  
3 windowing means, said means for applying said 2M-point frequency domain transform,  
4 said means for calculating said plurality of frequency domain level estimates, said  
5 frequency domain gain coefficients calculating means, said inverse frequency domain  
6 transform applying means, and said convolving means.

1 49. The frequency-warped processing system of claim 38, wherein said  
2 means for applying said frequency domain transform uses a transform selected from the  
3 group consisting of discrete Fourier transforms, fast Fourier transforms, Goertzel  
4 transforms, and discrete cosine transforms.

1 50. The frequency-warped processing system of claim 38, further  
2 comprising:

3 an input transducer, said input transducer converting audio input signals to  
4 analog input signals; and

5 an analog-to-digital converter, said analog-to-digital converter converting  
6 said analog input signals to said digital input signals.

1 51. The frequency-warped processing system of claim 38, further  
2 comprising:

3 a digital-to-analog converter, said digital-to-analog converter converting  
4 said digital output signals to analog output signals; and

5 an output transducer, said output transducer converting said analog output  
6 signals to an audio output.

1 (52.) A signal processing system, comprising:  
2 an input signal channel providing digital input signals;  
3 means for calculating a power spectrum for said digital input signals;  
4 means for applying a second difference operator to said power spectrum to  
5 locate a plurality of power spectrum peaks;  
6 means for amplifying said plurality of power spectrum peaks to achieve a  
7 modified power spectrum; and  
8 means for producing a digital output signal from said modified power  
9 spectrum.

1 53. The signal processing system of claim 52, further comprising  
2 means for determining the sharpness of each of said plurality of power spectrum peaks.

1 54. The signal processing system of claim 53, wherein said amplifying  
2 means applies a scaling factor to the amplification applied to each of said plurality of  
3 power spectrum peaks, said scaling factor based on the determined sharpness of the peak.

1 (55.) A method of processing sound in a hearing aid, comprising the  
2 steps of:

3 receiving digital input signals;

4 passing a portion of said digital input signals through a plurality of  
5 cascaded all-pass filters to form a sequence of delayed samples;

6 windowing said sequence of delayed samples;

7 applying a frequency domain transform to said windowed sequence of  
8 delayed samples to form a warped sequence;

9                   calculating a plurality of frequency domain level estimates from said  
10 warped sequence;  
11                   calculating a plurality of frequency domain gain coefficients from said  
12 plurality of frequency domain level estimates to form a warped time-domain filter;  
13                   calculating a plurality of spectral enhancement gain coefficients from said  
14 warped sequence;  
15                   calculating a plurality of compression-spectral enhancement gain  
16 coefficients from said plurality of frequency domain gain coefficients and said plurality of  
17 spectral enhancement gain coefficients;  
18                   applying an inverse frequency domain transform on said plurality of  
19 compression-spectral enhancement gain coefficients to form a set of time-domain filter  
20 coefficients; and  
21                   convolving said sequence of delayed samples with said set of time-domain  
22 filter coefficients to produce a digital output signal.